A Framework for Evaluating the Cost-Effectiveness of Mitigation Measures

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Earthquakes in 1999 caused damage in Istanbul and pointed to it as one of the world's mega cities with the greatest future damage and loss potential from the earthquake hazard. As a result, various kinds of mitigation measures are being applied. There is now an opportunity to bring together earth scientists, engineers and social scientists from Turkey and the United States to evaluate the cost-effectiveness of these measures using empirical data and field surveys.

This paper outlines a framework for evaluating the attractiveness of mitigation measures for reducing direct and indirect losses from earthquakes to apartment dwellers residing in a section of Istanbul (*e.g.* Avcilar). After characterizing the different elements of the framework and suggesting data needs for a pilot study, we outline the nature of the benefit-cost analyses for evaluating alternative mitigation strategies. The paper concludes by raising a set of questions that need to be addressed before one can initiate this research.

NATURE OF THE FRAMEWORK

Figure 1 depicts the framework in the context of apartment buildings that are subject to earthquake damage. It builds on concepts developed in a report by the Heinz Center (1999) and by Kleindorfer and Kunreuther (1999).

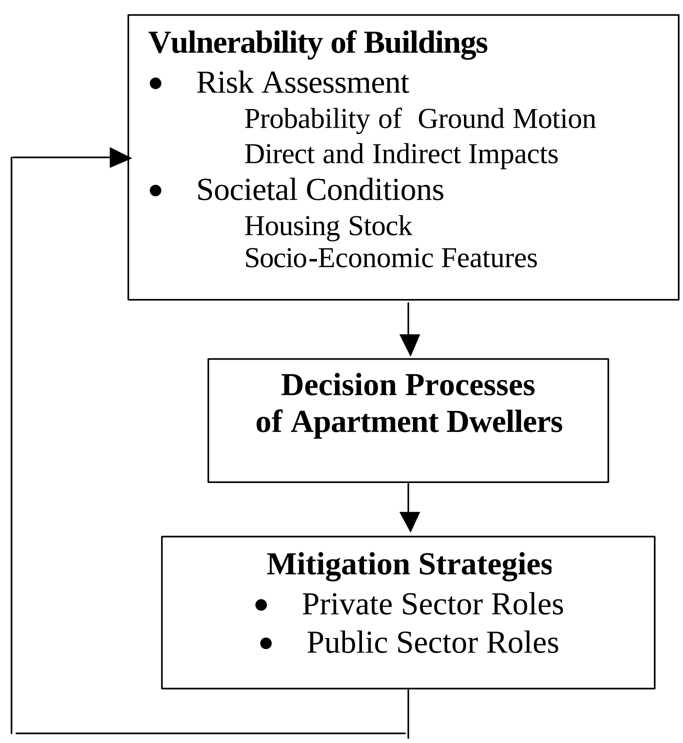

Figure 1: Framework for Analyzing Mitigation Strategies

The ingredients for evaluating the **vulnerability of buildings** to earthquakes or other natural hazards are broadly categorized as risk assessment and societal conditions. Ideally a *risk assessment* specifies the probability of events of different intensities or magnitudes occurring and the direct and indirect impacts of these events to the affected interested parties. *Societal conditions* include the residential structures and those who inhabit them, along with their socio-economic features (*e.g.,* age, education, income).

One also needs to understand the **decision processes** of the residents in the area. The term *decision processes* refers to the type of information and data collected by these individuals and how they are utilized in making choices. Unless we understand the nature of the decision processes of apartment dwellers in Istanbul, we will have a difficult time recommending specific programs or policies. If he or she is considering whether to seismically strengthen his or her home to reduce future losses from a severe earthquake (e.g., invest in new shear walls) the following questions naturally arise:

- What information does he or she collect on both the hazard itself and the potential damage with and without this mitigation measure?
- What type of decision rule(s) does he or she utilize in determining whether or not to invest in this mitigation measure?
- What type of data and decision rules do other key interested parties in the private and public sectors utilize in evaluating the cost-effectiveness of different mitigation measures?

Based on an understanding of the vulnerability of the building and the decision processes of the apartment dwellers, one needs to develop a disaster management program for reducing losses and providing financial protection to victims of future disasters. A **mitigation strategy** will normally involve a combination of private and public sector initiatives and may be used in combination with other policy tools such as insurance.

Let us look at the components of the framework in more detail.

Vulnerability Of Buildings

In determining the vulnerability of a building to earthquakes, one needs first to estimate the probabilities of ground motion at different frequencies and amplitudes, i.e., the hazard for that site. This hazard depends on the ground motion potential from each earthquake source at the site, either a fault or a zone of distributed seismicity. The ground motion potential is determined by the magnitude range and associated probabilities for each source, and by the seismic-wave attenuation from the source to the site. Finally, geologic characteristics of the site may affect the ground motion and they also need to be considered.

Earthquake hazard is a statement about the future based primarily on data about the past. By examining geologic records of prehistoric events, instrumental records of recent events, and by measuring the response of the ground to shaking, scientists keep learning more about the location, severity, frequency of occurrence, and physical effects of future earthquakes. Although uncertainties are still large, they are shrinking due to more reliable assessment procedures.

In the case of Istanbul, the earthquakes in 1999 caused large amounts of damage and losses, but these data greatly contributed to our understanding of future seismicity in the region and its effects on the built environment. In 1999 the plate boundary failed east of Istanbul thus stressing the portion of the boundary closest to the city. By quantifying this phenomenon, scientists have reached a consensus that most people residing in Istanbul are more likely than not to experience a major earthquake during their lifetime akin to several well-documented historic events that destroyed that city. [(e.g., Parsons et al 2000].

Next, the *impact of the ground motion on the building* can be predicted on the basis of its design and construction. Engineers have focused on the nature, distribution, and level of damage from earthquakes. Such investigations have increased our understanding of the performance of various types of buildings and structures over a wide range of ground motion.

The process of assembling the data on geologic and engineering data can be facilitated by geographic information systems (GIS). GIS may combine data on past quakes with modeling capabilities for estimating future disasters. It enables scientists to efficiently estimate the average rate of loss from earthquakes, but also the damage expected from specific earthquake scenarios. (King and Kiremidjian 1997).

Based on this information, one can construct an **exceedance probability (EP) curve** that depicts the annual probability that the damage or loss from a series of scenario events will exceed a certain value. The EP curve is the key element for evaluating a set of risk management tools. The accuracy of the EP curve depends upon the ability of natural hazard experts (*e.g.,* geologists and engineers) to estimate the impact of disasters of different magnitudes on different structures. Figure 2 depicts a hypothetical EP curve for a residential structure in an earthquake prone area of Istanbul without mitigation in place. The confidence intervals surrounding the mean EP curve indicate the uncertainty surrounding exceedance probability estimates, as well as the damage estimates from earthquakes of different magnitudes.[1] We need to understand how the mean EP curve shifts downward and how the confidence intervals change as one imposes specific mitigation measures (*e.g.* structural upgrading, nonstructural bracing) on the structure.

[1] For more details on how these confidence intervals were constructed, see Grossi et al. (1999).

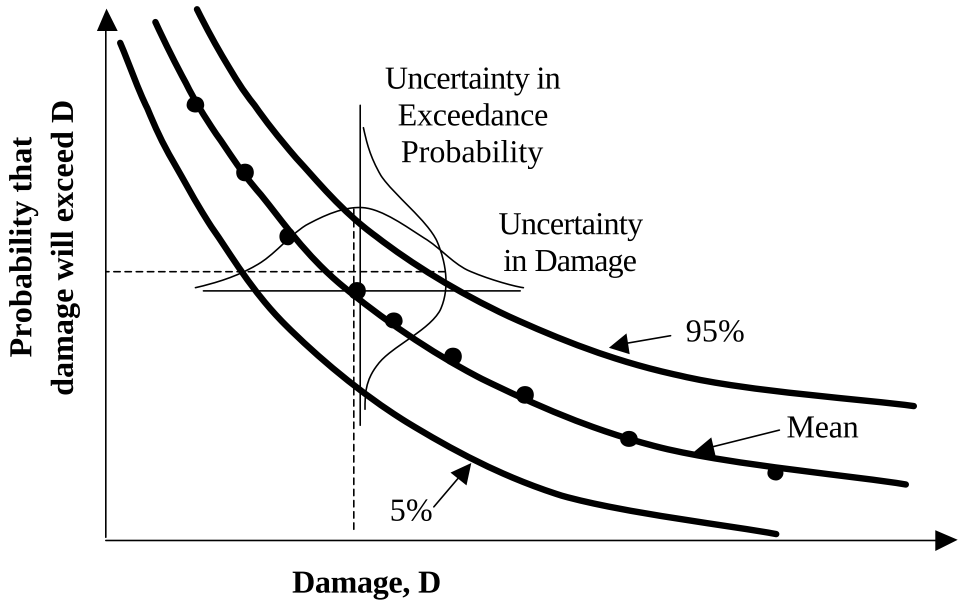

Figure 2: Example of Exceedance Probability (EP) Curve for a Residential Structure without Mitigation.

Turning to the *socio-economic features* of apartment dwellers, we need to know residents' income, education, age and other characteristics in order to be able to determine what types of policies and programs should be designed to deal with their vulnerability to future earthquakes. For example, most low-income residents will not be able to afford mitigation measures and hence will not retrofit their house (*e.g.* seismically strengthen it) unless they receive some type of grant or highly subsidized loan from the government. By knowing the composition of the relevant population, one can develop appropriate strategies for dealing with their situation.

Decision Processes of Apartment Dwellers

It is important to understand under what circumstances apartment dwellers are willing to invest in a cost-effective risk mitigation measure (RMM) voluntarily. The RMM will be deemed cost effective if the expected benefits in terms of reduction of damage discounted by an appropriate interest rate, exceeds the cost of the measure itself. If a mitigation measure meets this criterion, then it will certainly be viewed as desirable from a broader perspective when considering other direct and indirect benefits. These include saving lives, the savings from not being forced to move to a public shelter as well as the joys of being able to remain in one's home. We discuss these indirect impacts below when considering the type of cost-benefit analysis that needs to undertaken.

There is a growing empirical literature that provides insight into the typical individual in an earthquake-prone region in the United States who has to determine whether or not to invest in a protective measure. It is still an open question as to whether this behavior characterizes the decision processes of apartment dwellers in Istanbul.

In a 1989 survey of 3,500 homeowners in four California counties subject to earthquake damage, only between 5 and 9 percent of the respondents in each of these counties reported adopting any earthquake mitigation measures (Palm et. al. 1990). A follow-up survey of residents affected by the October 1989 Loma Prieta earthquake and the Northridge earthquake of 1994 revealed that only 10 percent of homeowners invested in any type of structural loss-reduction measure whether or not they were affected by recent earthquakes in the state (Palm 1995). Some mitigation measures that are not adopted voluntarily are relatively inexpensive and cost-effective. For example strapping a water heater to prevent it from falling over can be undertaken at a cost of under $5 in materials and one hour of a person's time. (Levenson 1992).

There are five principal reasons why property owners and renters do not appear to want to invest in cost-effective mitigation measures. More detail can be found in Kunreuther (1996):

Short Time Horizons Individuals may have relatively short time horizons over which they want to recoup their investment in a mitigation measure. Even if the expected life of the house is 25 or 30 years, the person may only look at the potential benefits from the mitigation measure over the next 3 to 5 years. They may reason that they will not be residing in the property for longer than this period of time and/or that they want a quick return on their investment.

High Discount Rates The need for a quick return is also consistent with having a high discount rate regarding future payoffs. Loewenstein and Prelec (1992) propose a behavioral model of choice whereby the discount function is hyperbolic, rather than exponential. Their model appears to explain the reluctance of individuals to incur the high immediate cost of energy-efficient appliances in return for reduced electricity charges over time.

Underestimation of Probability Some individuals may perceive the probability of a disaster causing damage to their property as being sufficiently low that the investment in the protective measure will not be justified. For example, they may relate their perceived probability of an earthquake (p) to a threshold level (p*), which they may unconsciously set, below which they do not worry about the consequences at all. If they estimate $p < p^*$, then they assume that the event "will not happen to me" and take no protective actions.

Aversion to Upfront Costs If people have budget constraints, then they will be averse to investing in the upfront costs associated with protective measures simply because they feel they cannot afford these measures. It is not unusual for one to hear the phrase: "We live from payday to payday" when asked why a household has not invested in mitigation measures.

Truncated Loss Distribution Individuals may have little interest in investing in protective measures if they believe that they will be financially responsible for only a small portion of their losses should a disaster occur. If their assets are limited in relation to their estimated potential loss, then these individuals may feel they that they can walk away from their destroyed home without being financially responsible. Similarly, if residents anticipate liberal disaster relief from the government should they suffer damage, then they would have less reason to invest in a cost-effective mitigation measure.

Mitigation Strategies

Mitigation is a central policy tool in developing a disaster management strategy for reducing future damage as well as lowering the financial costs of future disasters. It is a natural complement to the Turkish Catastrophe Insurance Pool (TCIP), which became effective in March of 2001. Under TCIP all property owners are required to purchase insurance to protect their property (not contents) against damage from earthquakes and perils such as fires and landslides triggered by earthquakes.[2] Below we suggest two ways that mitigation can be linked with insurance that could be considered as part of a more comprehensive disaster management strategy for Turkey.

Premium Reductions Linked with Government Mitigation Loans Property owners may voluntarily adopt mitigation measures if they are rewarded monetarily by receiving some financial benefit. Since insurance is compulsory in Turkey, one way to do this would be to provide premium reductions to reflect the lower damage that would be experienced from future earthquakes. If individuals are reluctant to incur the upfront cost of mitigation due to budget constraints, then one way to make this measure financially attractive to the property owner is to provide funds for mitigation through some type of long-term government loan. To illustrate, a 20-year loan for $1500 to strengthen the building at an annual interest rate of 10% would result in payments of $170 per year. If the expected annual reduction in losses was greater than $170 and the insurance premium reflected this, then the insured property owner would have lower total payments by investing in cost-effective mitigation than not doing so.

The challenge for strengthening apartment buildings in Turkey is that one would have to obtain agreement by all the owners of the units to invest in the mitigation measure for the structure. This is a near impossible task unless the TCIP required that the loss reduction measure be put in place and then it reduced the premiums to everyone residing in the building. If the mitigation measure reduced the expected annual damage to each individual unit by more than the annual loan cost, this would not present any problems. In this case the total cost to the property owner would be less than it would be if the RMM were not adopted. Suppose, however, that the expected discounted direct and indirect benefits of a mitigation measure exceeded the expected costs but the premium reductions (which are based solely on the direct benefits) was less than the annual loan costs. Then the property owner might be reluctant to agree to have the building retrofitted. If there was consensus by the government that retrofitting was still worthwhile

[2] For more details of the current earthquake insurance system in Turkey, see Gulkan (2001).

then some type of subsidized loan might be necessary to make mitigation a palatable alternative.

There may be other reasons for subsidized loans. Many poorly constructed buildings are occupied by low-income families who cannot afford the costs of mitigation measures on their existing structure or the costs of reconstruction should their house suffer damage from a natural disaster. Equity considerations argue for providing this group with low interest loans and grants for the purpose of adopting cost-effective mitigation measures or for them to relocate to a safer area. Since low-income victims are likely to receive disaster assistance from the government, subsidizing these mitigation measures can also be justified by showing that they reduced expected hazard/disaster-related costs incurred by the government both before and after an earthquake.

Well-Enforced Building Codes Retrofitting structures can reduce future losses but require inspections and enforcement procedures. Building codes mandate that property owners adopt mitigation measures. Such codes may be desirable when property owners would otherwise **not** adopt cost-effective measures because they either misperceive the benefits from adopting the measure and/or underestimate the probability of a disaster occurring. If a family is forced to vacate its property because of damage that would have been prevented if a building code had been in place, then this additional cost needs to taken into account by the public sector when evaluating the cost-effectiveness of a mitigation measure from a societal perspective.

Cohen and Noll (1981) provide an additional rationale for building codes. When a structure collapses, it may create externalities in the form of economic dislocations that are beyond the physical damage suffered by the owners. These may not be taken into account when the owners evaluate the importance of adopting a specific mitigation measure. For example, if a building topples off its foundation after an earthquake, it could break a pipeline and cause a major fire that would damage other structures not structurally damaged by the earthquake in the first place.

DATA NEEDS FOR TURKEY

In order to undertake a detailed mitigation study in Turkey we will need the following data on the probability and consequences of earthquakes in the region as well as the uncertainty surrounding these estimates. We propose to undertake an analysis on prototype buildings in one or two districts in Istanbul that are particularly vulnerable to earthquakes (e.g., Avcilar) and use this as a prototype for future studies of larger areas, and use this as a prototype for future studies.

Knowledge Databases

These databases consist of the geological, geotechnical and structural engineering data provided by GIS systems. The following databases are important in characterizing the earthquake risk.

- ***Earthquake Source Database:*** Identifies the seismic sources that define the earthquake threat for the region (*e.g.* Istanbul). These sources are characterized by their geometry (*e.g*, length, width, depth, dip angle), maximum magnitude, recurrence relationship, and attenuation from source to site. These data may include probability of rupture on a fault segment conditional on the timing of previous ruptures and thus provide time-dependent hazard estimates.

- ***Geotechnical Hazard Database:*** Includes the soil classification scheme and specific site characteristics, including the potential for liquefaction, landslide, and fault rupture in the study region.

- ***Vulnerability Database:*** Defines the engineering principles which relate ground motion characteristics and damage ratio for different types of structures in the study region.

Analytical Algorithms

These algorithms comprise empirically derived formulas used to compute the damage and subsequent losses from earthquakes in a particular location. First, a set of scenario earthquake events is constructed for determining damage at the site. Then, the site-specific ground motion spectra (and possibly also consistent time-histories) are calculated for each selected event. In this case, a "site" will be the centroid of a geo-unit, such as a postal code, that would be selected to undertake the calculations. Then, the damage is calculated for each category of exposure, in this case apartment buildings. Finally, the loss is derived from the damage, considering the values at risk and any savings obtained by mitigation measures such as seismically strengthening a residential structure.

Exposure Database

The exposure database includes the construction characteristics of each exposure category (in this case, residential structures), the socio-economic characteristics of the exposure's inhabitants, and the geographical distribution of the exposure. The distribution is related to the geo-units, which represent geographical cells (*e.g.* postal code) used for aggregation purposes.

Apartment Dwellers Attitudes toward Risk, Mitigation and Building Codes

There is a need for surveys of apartment dwellers (both renters and owners of their unit) in Istanbul to determine the role mitigation can play in dealing with the earthquake risk. The surveys would examine the factors that influence the adoption of mitigation measures including the individuals' perceptions of the risk from the hazard, the role of past experience and social contacts, the benefits of mitigation and their attitudes toward well-enforced building codes.

A survey of apartment dwellers' perceptions of the earthquake risk in Istanbul has already been completed (Fiske et al. 2001) and another one on their attitudes toward mitigation measures will be shortly underway (Onculer 2001). We will utilize the findings of both these surveys to characterize apartment dwellers' attitudes toward earthquake risk mitigation and building codes.

Attitudes and Knowledge of Key Interested Parties

It would also be useful to undertake a series of interviews with building construction officials and engineers, as well as municipal and government officials, to determine their attitudes towards building codes and construction practices. What mitigation measures are they currently considering? What is the perceived cost-effectiveness for new and existing structures? These data will be used in evaluating various seismic hazard scenarios with and without mitigation measures and well-enforced building codes.

Developing Alternative Mitigation Strategies

A comparison of building code enforcement procedures in the US and Turkey may yield some interesting comparative lessons. There may also be ways of encouraging enforcement of building codes and mitigation measures through long-term liability insurance required for contractors with premiums based on risk. To the extent that the government continues to be the primary risk-bearing institution, as it is currently in Turkey, a model like the US flood insurance program could be considered.[3]

UNDERTAKING COST BENEFIT ANALYSES OF MITIGATION

Once these data are collected, one can undertake a detailed cost-benefit analysis (CBA) of alternative mitigation measures and strategies for implementing them. These analyses can begin with a single scenario and then be extended to multiple scenarios. Both of these cases are briefly described below:

Deterministic Case

Consider the case of a specific earthquake with a given magnitude occurring at a specific location that causes a certain amount of damage to a residential structure. We would want to have the following information:

Direct Damage Module This would depict the physical damage to the structure with and without mitigation. This module will ***not*** *have* a time component associated with it.

[3] For more detail on the National Flood Insurance Program in the United States see Pasterick (1998).

Indirect Loss Modules These modules will characterize the losses to residents over and beyond the direct physical damage. For example, if a family has to be moved to a public shelter, there are negative impacts on their quality of life and economic costs to the government for providing food and other amenities while they are displaced from their home. These modules will have a time component associated with them (*e.g.* number of days/weeks that residents are displaced from their homes with and without mitigation in place)..

Probabilistic Case

To undertake a multiple scenario analysis, we will need to generate a set of earthquakes of different magnitudes and occurring at different locations and undertake the same type of analysis specified above for the single scenario case. We then consider the outcomes (*e.g.*, damage or loss) for each specific earthquake in terms of the annual recurrence time of that earthquake.[4]

Sensitivity Analyses

Here are the types of sensitivity analyses that one could undertake:

Annual Recurrence of Earthquakes What impact will changes in the annual recurrence of earthquakes of a given magnitude have on the costs and benefits specified above for each module?

Discount Rate What impact will changes in the annual interest rate used to discount future benefits and costs have on the cost benefit analysis?

Implementation Strategies

For each mitigation measure that is viewed as cost-effective, one needs to consider the most desirable implementation strategy for investigating these approaches. In particular, here are some issues that need to be considered.

- What economic incentives are most appropriate for encouraging apartment dwellers to adopt mitigation measures?
- What special treatment should be given to low income residents to encourage them to adopt mitigation measures (*e.g.* subsidized government loans or grants)?
- If certain building codes are deemed appropriate (*e.g.* bracing all homes in Avcilar), how can one maximize the chance that they are being enforced?

[4] For more information on the probabilistic case considered in previous analyses, see Grossi (2000).

QUESTIONS FOR DISCUSSION

Below we have raised a set of questions that need to be addressed before one can take the next steps in integrating science, engineering and social science for examining the cost-effectiveness of mitigation of residential structures in Istanbul:

Nature of Pilot Study

- What parts of Istanbul should be chosen for pilot studies of mitigation?
- Should we focus on one or two typical buildings (e.g. multi-story apartments of a particular type of construction)?
- What fraction of residents in apartment buildings are renters and what fraction are owners?
- What proportion of the apartment building owners actually reside there?
- Should we undertake a benefit cost analysis of mitigation for renters as well as owners?
- Should we consider the costs and benefits of retrofitting a structure as well as new construction with and without specific design features?

Available Data Bases

- What knowledge databases are available for these pilot study areas?
- How accurate is the mean damage exceedance probability (EP) curve based on the knowledge databases for the pilot study areas of Istanbul?
- Can one plot confidence intervals or other uncertainty bounds with respect to this mean damage EP curve?

Mitigation Measures

- What type of mitigation measures should be considered?
- What mitigation measures are currently being implemented in Istanbul?
- What is motivating these investments?
- Is the investment more likely if the owner lives in the building?
- What impact does each of these mitigation measures have on the mean damage EP curve and the confidence interval surrounding it?
- What impact does each of these mitigation measures have on the mean loss EP curve and the confidence interval surrounding it?

Evaluating Costs and Benefit of Mitigation

- What cost information is available on these mitigation measures?
- What information is available on the benefits from mitigation to construct direct and indirect damage modules?
- What data are available on the composition of residential structures in the area?
- Has anyone developed calibrated models of structural behaviors for the residential housing stock?
- What data are available on socio-economic characteristics of residents living in these structures (*e.g.,* age, education, annual income)?

- What programs should be considered to put leverage on the owners of the apartment units and/or owners of the building to adopt cost-effective mitigation measures?
- What role can TCIP play in encouraging the adoption of mitigation measures in Turkey?

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